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M. Zarwodny

NATIONAL DEFENSE RESEARCH COMMITTEE

ARMOR AND ORDNANCE REPORT NO. A-237 (OSRD NO. 3028)

DIVISION 2

THE INFLUENCE OF SPECIMEN DIMENSIONS AND SHAPE ON THE RESULTS OF TENSILE IMPACT TESTS

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D. S. Wood, P. E. Duwez

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Approved on December 8, 1943
for submission to the Division Chief

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Preface

The work described in this report is pertinent to the projects designated by the Navy Department Liaison Officer as NO-11 and NS-109 and to Division 2 project P2-303.

This work was carried out and reported by the California Institute of Technology under Contract OEMsr-348.

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for armor and ordnance edited
this report and prepared it for duplication.

CONTENTS

List of figures

THE INFLUENCE OF SPECIMEN DIMENSIONS AND SHAPE ON THE RESULTS OF TENSILE IMPACT TESTS

Abstract

This report presents the results of a study on the influence of specimen length, diameter and cross-sectional shape on tensile impact tests. Part I deals with the effect of the ratio of length to diameter; Part II, with the effect of size in geometrically similar specimens, and Part III, with the influence of cross-sectional shape. The results show that the effect of velocity on the tensile properties of metals is independent of both the dimensions and the cross-sectional shape of the specimen. Furthermore, the critical velocity is not altered by these variables.

1. Introduction

In the field of materials testing, it is important to recognize the influence of dimensions and shape of the test specimen on the results. For some time, tensile impact tests at the Impact Testing Laboratory of the California Institute of Technology have been made on specimens having a diameter of 0.30 in. and a gage length of 8 in. In a previous report[1] an effort was made to cover one phase of this problem -- namely, the effect of varying the gage length of a specimen having a constant diameter of 0.30 in. In that report, it was shown that while the values of percentage elongation were decreased with increased gage length, the velocity at which the elongation decreased was not modified. However, it was shown that determination of the critical velocity[2] was more difficult if the gage length was below about 4 in. for a specimen with a diameter of 0.30 in. In other words, it is necessary that the ratio of the length to the diameter be at

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1/ P. E. Duwez, D. S. Wood, D. S. Clark, The influence of specimen length on strain propagation in tension, NDRC Report A-105 (OSRD No. 957), Oct. 1942.

2/ P. E. Duwez, D. S. Wood, D. S. Clark, The propagation of plastic strain in tension, NDRC Report A-99 (OSRD No. 931), Oct. 1942.

least 13. Further investigations have been made to determine the effect of the ratio of length to diameter on the results of tensile impact tests. This aspect is covered in Part I of this report.

In order to carry this investigation further, static and dynamic tensile tests have been made on specimens that have different dimensions, but are geometrically similar. The principle of similitude implies that if the structure of a metal is perfectly uniform, the static tensile properties of geometrically similar specimens should be the same. However, under dynamic conditions, geometrically similar specimens are not subjected to the same average rate of strain at the same impact velocity. If the average rate of strain does exert an influence, geometrically similar specimens should exhibit different dynamic tensile properties. To test this assumption, an investigation has been made to determine whether or not geometrically similar specimens tested at the same impact velocity exhibit identical dynamic tensile properties. In Part II of this report, the results of a study on this second phase of the problem are presented.

There has been a question in the minds of some critics as to the applicability of tensile impact results based on specimens of circular section to other cross-sectional shapes. To answer this question, static and dynamic tensile tests have been made on specimens of circular, square, and rectangular cross section. The third part of this report discusses the results of these tests.

PART I. RATIO OF LENGTH TO DIAMETER

2. Material tested

The material used in this part of the investigation was a cold-rolled steel of Rockwell B hardness 87-91 having the following analysis:

	Percent
Carbon	0.19
Manganese	1.03
Phosphorus	0.018
Sulphur	0.029
Silicon	0.34

It should be noted that this steel is not exactly the same as the one used in a previous investigation[3/] on the influence of specimen length on the results of dynamic tests. The diameter D, the length L, and the ratio L/D, of the specimens tested are given in Table I.

3. Testing procedure

Two static tests made in the manner previously described[4/] were performed on each series of specimens. The rotary impact testing machine described in the same reference was used for the dynamic tests. In both types of tests, measurements of energy per unit volume required to rupture the specimen, the percentage elongation and the percentage reduction of area, were taken for each specimen.

4. Discussion of the results

(a) Static tests. -- The stress-strain diagrams given in Fig. 1 were obtained by graphing the apparent stress in pounds per square inch as a function of the average strain in percent. The proportional limit, ultimate strength, percentage elongation, energy per unit volume, and the reduction of area are given for each specimen in Table I. It is apparent that for a constant diameter and a varying gage length, the stress-strain curves are nearly identical up to that strain at which the tangent to the curve is horizontal. Beyond this point, the shape of the curves is controlled by the necking. This matter has been discussed in a previous report[5/]. The table demonstrates also that the ultimate strength varies only slightly from specimen to specimen, its average value being 95,000 lb/in^2.

The critical velocity has been computed by the von Kármán formula[6/] for all the specimens tested and is found to vary between 85 and 91 ft/sec and to have an average of 88.4 ft/sec. These figures are given in Table I.

3/ Reference 1.

4/ Reference 1.

5/ Reference 1.

6/ Th. von Kármán, On the propagation of plastic deformation in solids, NDRC Report A-29 (OSRD No. 365), Jan. 1942.

Table I. Results of static tests of cold-rolled steel; diameter D of specimens, 0.15 in.

Gage Length L (in.)	Ratio L/D	Proportional Limit (lb/in²)	Ultimate Strength (lb/in²)	Elongation in Gage Length (percent)	Energy per Unit Volume (ft lb/in³)	Theoretical Critical Velocity (ft/sec)	Reduction of Area (percent)	Hardness Rockwell B
1	6.7	70 000	94 000	9.0	652	85	53.0	91.8
1	6.7	71 000	94 300	9.5	628	87	54.0	94.6
2	13.3	67 000	95 000	7.1	405	90	58.2	92.5
2	13.3	68 000	95 000	7.2	400	91	56.3	93.7
3	20.0	68 500	95 000	5.1	394	88	59.1	92.7
3	20.0	70 000	95 000	4.8	356	90	60.2	92.7
4	26.6	70 000	95 500	3.5	256	87	63.0	95.0
4	26.6	71 500	94 500	3.4	254	89	64.1	91.1

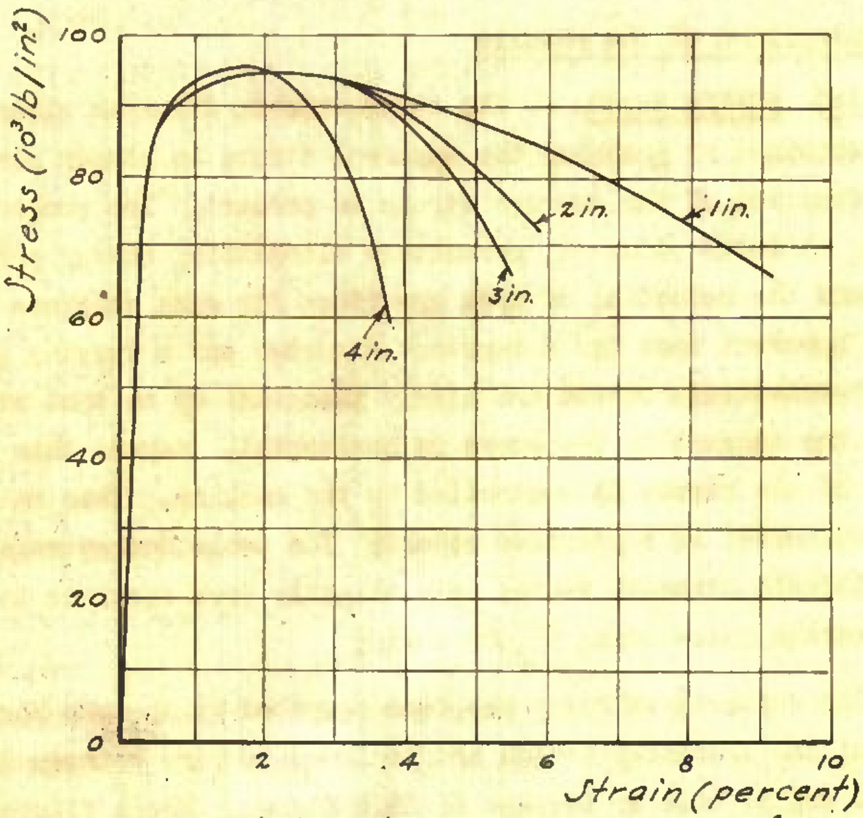

Fig. 1. Static stress-strain curves for cold-rolled steel; all the specimens are 0.15 in. in diameter; different gage lengths are indicated on the curves.

(b) Dynamic tests. -- The general results of the dynamic tests are given in Tables II and III. The curves of percentage elongation and energy per unit volume absorbed to rupture the specimen, each versus impact velocity are presented in Fig. 2. For the 1-in. specimens, the location of the maximum is difficult to determine, making a critical velocity very difficult to detect. However, a distinct maximum is observed for the 2- and 3-in. specimens and the critical velocity can be measured at about 100 ft/sec. In the case of the 4-in. specimen, the maximum places the critical velocity at a figure somewhat lower than that obtained with the 2- and 3-in. specimens. This difference may be related to a structural difference existing in the specimens since the computed critical velocity for this 4-in. specimen was lower than that computed for the 2- and 3-in. specimens. However, as previously reported[7], the results show that though the critical velocity does not depend on the length of the specimen, it is less distinct in tests made on shorter specimens.

These results also show that it is not possible to determine accurately the critical velocity in a specimen 0.150 in. in diameter and 1 in. long, whereas such a determination is possible when the gage length is 2 in. or more. In Report A-105, it was shown that for specimens of 2-in. gage length and 0.300-in. diameter the curves of energy and percentage elongation versus impact velocity were also too flat to detect a critical velocity, but, in this case again, a specimen of 4-in. gage length gave a distinct maximum. It is logical to believe that the ratio of gage length to diameter is the determining factor. Therefore, it is concluded that a distinct maximum, indicating the critical velocity, will appear in the energy and percentage elongation versus impact velocity curves if the ratio L/D is of the order of 13 or greater.

5. Conclusions

The results of this investigation together with those presented in a former report lead to the conclusion that the critical velocity

7/ Reference 1.

Table II. Results of dynamic tests of cold-rolled steel; specimens 0.15 in. in diameter, 1 and 2 in. long.

Specimen No.	Impact Velocity (ft/sec)	Ultimate Strength (lb/in^2)	Energy per Unit Volume ($ft\ lb/in^3$)	Elongation in Gage Length (percent)	Reduction of Area (percent)	Hardness Rockwell B
			1-in. Gage Length			
3	26.0	108 000	1450	17.0	52	92.2
7	49.8	114 000	1230	15.8	50	92.1
5	49.8	106 000	1530	18.6	59	93.0
6	75.0	95 000	1080	17.5	58	91.4
13	101.0	111 000	1190	15.3	68	90.1
4	101.0	102 000	1130	15.7	58	92.4
8	126.0	104 000	805	13.1	60	91.6
9	150.0	104 000	737	9.7	52	92.2
14	150.8	109 000	856	12.6	62	91.5
10	176.0	115 000	907	11.9	51	92.0
11	176.0	110 000	840	12.1	60	92.0
12	201.0	112 000	907	12.5	61	91.7
					Average	91.8
			2-in. Gage Length			
2	25.0	107 000	--	9.0	58	93.8
9	49.5	123 000	1001	10.6	61	92.6
3	50.0	--	--	11.5	58	93.4
4	74.2	112 000	1160	12.7	61	92.8
10	100.0	110 000	1360	13.2	59	92.9
5	125.0	125 000	1000	9.3	61	94.2
6	152.0	115 000	712	7.1	60	93.0
7	181.0	110 000	613	7.7	61	93.8
8	200.0	119 000	575	6.8	61	92.5
					Average	93.2

Table III. Results of dynamic tests of cold-rolled steel; specimens 0.15 in. in diameter, 3 and 4 in. long.

Specimen No.	Impact Velocity (ft/sec)	Ultimate Strength (lb/in^2)	Energy per Unit Volume ($ft\ lb/in^3$)	Elongation in Gage Length (percent)	Reduction of Area (percent)	Hardness Rockwell B
3-in. Gage Length						
5	24.7	106 200	642	8.3	58	93.8
6	50.5	97 000	750	9.4	45	96.6
4	75.0	107 000	764	10.7	53	93.9
3	75.1	---	---	8.9	56	93.2
8	99.0	---	---	8.3	53	94.1
7	101.0	105 000	925	9.8	59	93.5
14	125.0	104 000	680	8.7	64	93.1
10	150.0	100 000	453	6.2	59	92.3
11	151.0	100 000	460	7.0	52	93.7
12	176.0	99 000	456	5.6	58	93.5
13	204.0	101 000	382	5.1	62	93.2
					Average	93.7
4-in. Gage Length						
3	25.3	114 000	615	7.0	58	95.6
4	50.2	113 000	675	7.4	64	94.5
5	75.3	113 000	840	9.3	60	93.8
6	100.0	119 000	765	8.1	62	94.1
8	125.0	112 000	595	5.9	60	91.3
7	126.0	---	---	6.9	57	93.7
9	150.0	124 000	523	4.3	64	95.0
10	178.0	117 000	497	4.1	65	95.1
11	202.0	115 000	447	3.9	55	94.1
					Average	94.1

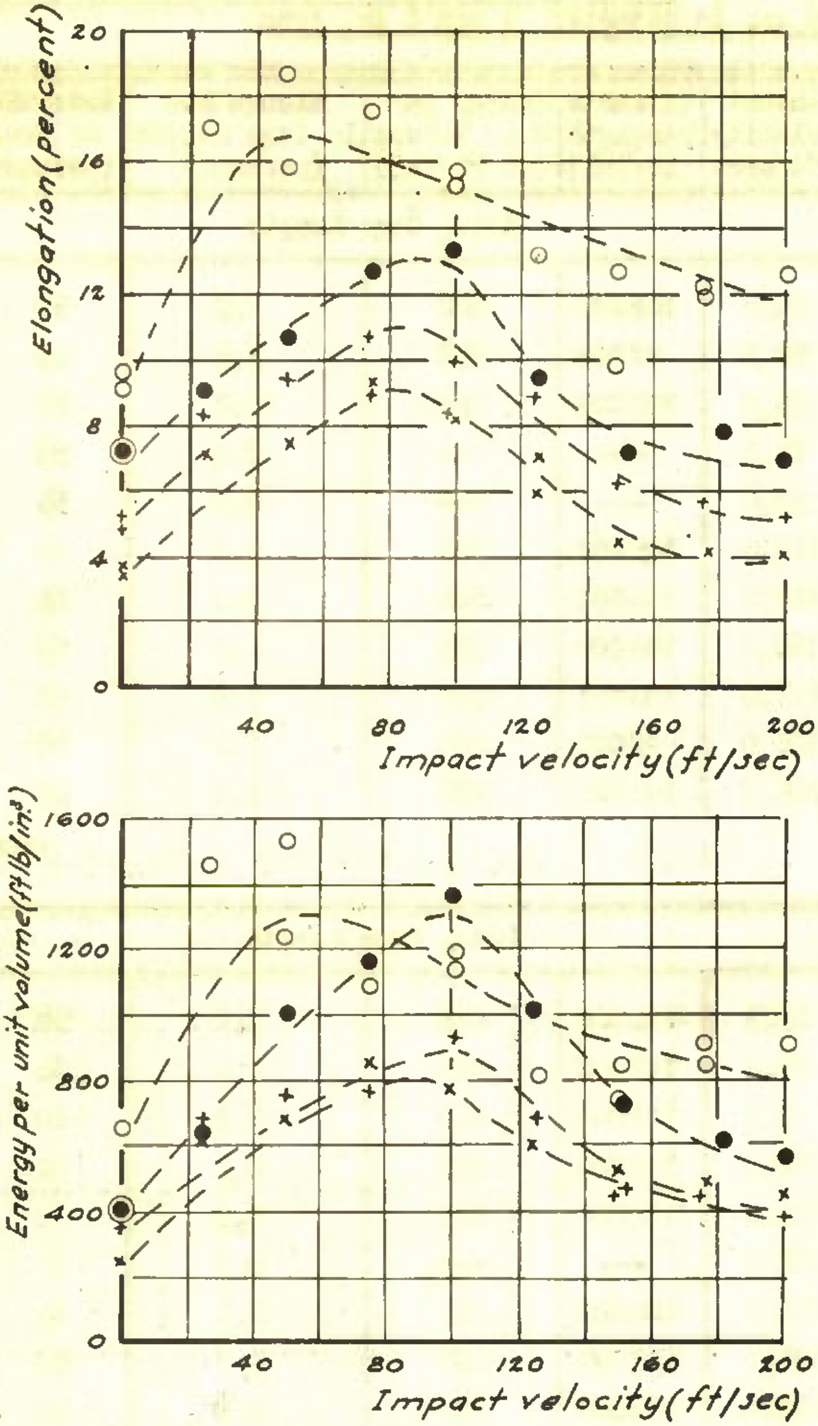

Fig. 2. Percentage elongation and specific energy, each versus impact velocity, for cold-rolled steel; all specimens are 0.15 in. in diameter; o, 1 in.; ●, 2 in.; +, 3 in.; and x, 4 in.

of a given material in a given structural condition is independent of the length of specimen provided the ratio of length to diameter is greater than 13. Furthermore, it may be concluded that, in order to determine the tensile critical velocity accurately, the ratio of gage length to diameter of the specimen must be at least 13.

PART II. SIZE EFFECT

6. Material tested

Annealed copper and the steel referred to in Part I were the two materials employed in this phase of the investigation. For static tests only, a series of specimens was taken from a 1-in. round bar of copper; another series was taken for both static and dynamic tests from a ½-in. round bar of copper. Tests were made on the steel in the cold-rolled and annealed conditions. The details of annealing treatments and specimen dimensions are given in Table IV.

Table IV. Specifications of specimens tested.

Metal	Annealing Temperature (°F)	Time at Temperature (hr)	Length $\underline{L}$ of Specimen (in.)	Diameter $\underline{D}$ of Specimen (in.)	L/D	Factor of Similitude	Tests Made
Copper Lot I, ½-in.	900	1	7 2	0.35 0.10	20.0 20.0	3.5 1	Static and Dynamic
Copper, Lot II, 1-in.	900	1	16 8 4	0.60 0.30 0.15	26.6 26.6 26.6	4 2 1	Static only
SAE 1020, Cold-rolled			8 4	0.30 0.15	26.6 26.6	2 1	Static and Dynamic
SAE 1020, Annealed	1600	1	8 4	0.30 0.15	26.6 26.6	2 1	Static and Dynamic

7. Discussion of results

(a) Static tests. -- Two static tests were made for each size of specimen machined from the $\frac{1}{2}$-in. copper bar. The static stress-strain curves are given in Fig. 3 and the results of the tests on this group of specimens are given in Table V. These results show that the small specimen, (2 in. long and 0.10 in. in diameter) has about the same ultimate strength, but a much smaller percentage elongation than the large specimen (7 in. long and 0.35 in. in diameter). This difference could be associated with a nonuniform structure in the cross section of the bar from which the specimens were cut. Therefore, another series of specimens was machined from another bar of copper 1 in. in diameter.

The latter series consisted of specimens of three different sizes as shown in Table V. Two static stress-strain curves were obtained for each specimen size; however, only one of each is presented in Fig. 4 since duplicate tests did not differ by more than 500 lb/in^2. A comparison of Fig. 3 with Fig. 4 makes it clear that the variation of elongation from specimen to specimen is much less for those machined from the 1-in. bar than for those machined from the $\frac{1}{2}$-in. bar.

It seems probable that the degree of influence exerted on the static tensile properties by specimen size is primarily dependent upon the equivalency of the structure of the different specimens.8/

The two stress-strain curves obtained for each specimen of cold-rolled steel and annealed steel are given in Figs. 5 and 6. Here the difference between the static properties of the two sizes of specimens is clearly defined. The small specimens 4 in. long and 0.15 in. in diameter exhibit a greater ultimate strength and less percentage elongation than the large specimens 8 in. long and 0.30 in. in diameter. A hardness survey of the cross section was made on the $\frac{1}{2}$-in. diameter

8/ While the stress-strain diagrams of the copper specimens of different sizes are approximately the same, it will be noted that there is an appreciable variation of hardness. An examination of the microstructure of these specimens indicated the same grain size. No explanation is given for this anomaly; however it is probable that this difference does not alter the conclusions of this investigation.

Table V. Results of static tests of geometrically similar specimens.

Metal	Specimen Size (in.)	Specimen No.	Ultimate Strength (lb/in²)	Prop. Limit (lb/in²)	Energy per Unit Volume (ft lb/in³)	Elongation in Gage Length (percent)	Reduction of Area (percent)	Theoretical Critical Velocity (ft/sec)	Experimental Critical Velocity (ft/sec)	Hardness Rockwell
Annealed copper, Lot I, ½ in.	7 × 0.35	2	29000	4 000	820	41.4	71	241	>200	74.8 F
	7 × 0.35	3	29500	4 000	845	42.4	70			73.0 F
	2 × 0.10	11	29000	4 000	670	32.8	68	222	>200	31.5 F
	2 × 0.10	12	29200	4 000	600	31.5	69			31.3 F
Annealed copper, Lot II, 1 in.	16 × 0.6	1	28400	4 000	756	38.0	69			38.0 F
	16 × 0.6	2	28200	4 000	768	39.6	70			40.0 F
	8 × 0.3	1	29400	4 000	756	37.6	75			65.6 F
	8 × 0.3	2	29300	4 000	670	34.0	70			64.3 F
	4 × 0.15	1	29700	4 000	715	34.6	72			39.5 F
	4 × 0.15	2	29500	4 000	706	34.8	75			38.0 F
Cold-rolled steel	8 × 0.3	L1	85500	65000	361	5.4	66	95	100	94.4 B
	8 × 0.3	L2	82500	64000	442	6.6	66			92.8 B
	4 × 0.15	S1	95500	70000	256	3.5	63	87	80	95.0 B
	4 × 0.15	S2	94500	71500	253	3.4	64			91.1 B
Annealed steel	8 × 0.3	L9	66800	40800	1070	21.6	68	183	140	73.3 B
	8 × 0.3	L10	67000	40400	1050	21.4	67			74.2 B
	4 × 0.15	S10	73000	43000	747	14.1	58	182	150	72.3 B
	4 × 0.15	S11	74000	44000	773	14.2	55			73.0 B

bar, from which the specimens were machined, for the purpose of establishing whether or not the difference in results could be related to nonuniformity. The hardness measurements were made with the superficial Rockwell Hardness Tester using the 45 T scale. The results are given in Fig. 7 for both cold-rolled steel and annealed steel. In the annealed bar very little if any variation in hardness was observed. In the cold-rolled steel, there was a slight decrease in hardness from the center of the bar to the periphery. Even so, the difference between the average hardness across a specimen 0.15 in. in diameter and one 0.3 in. in diameter is not large enough to account for the observed difference between the tensile properties of the various sizes of specimens.

In spite of the fact that hardness measurements did not reveal any measurable variations within a cross section, it is possible that the observed difference in tensile properties is a conseouence of a nonuniform distribution of impurities in the bar from which the specimens were machined. On the other hand, the surface characteristics of the material may be more influential in the case of a small specimen than a large one. In such a case a greater strength at the surface could account for the observed results.

(b) Dynamic tests. -- The dynamic tests were made at impact velocities ranging from 25 to 200 ft/sec. The results are given in Tables VI to VIII. The curves for energy per unit volume and percentage elongation, each versus impact velocity, are given in Figs. 8 to 10. For the annealed copper specimens the dynamic values of energy per unit volume and percentage elongation for the small specimens are less than the corresponding values for the large specimens. Also for annealed copper, the discrepancy found in the static tests is still present in the dynamic tests. There is an almost equal increase in ultimate strength under dynamic conditions for both kinds of specimens, as is shown in Table VI.

For the cold-rolled steel (Table VII) the curves of energy per unit volume and the percentage elongation, each versus impact velocity

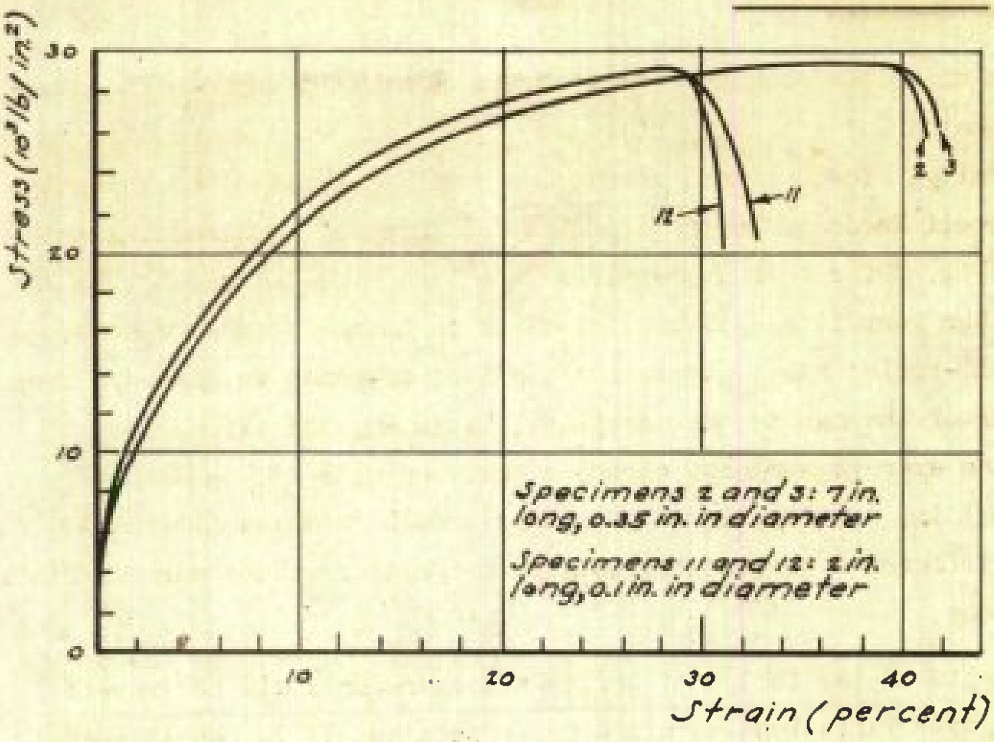

Fig. 3. Static stress-strain curves for annealed copper specimens machined from 1/2-in. round bar.

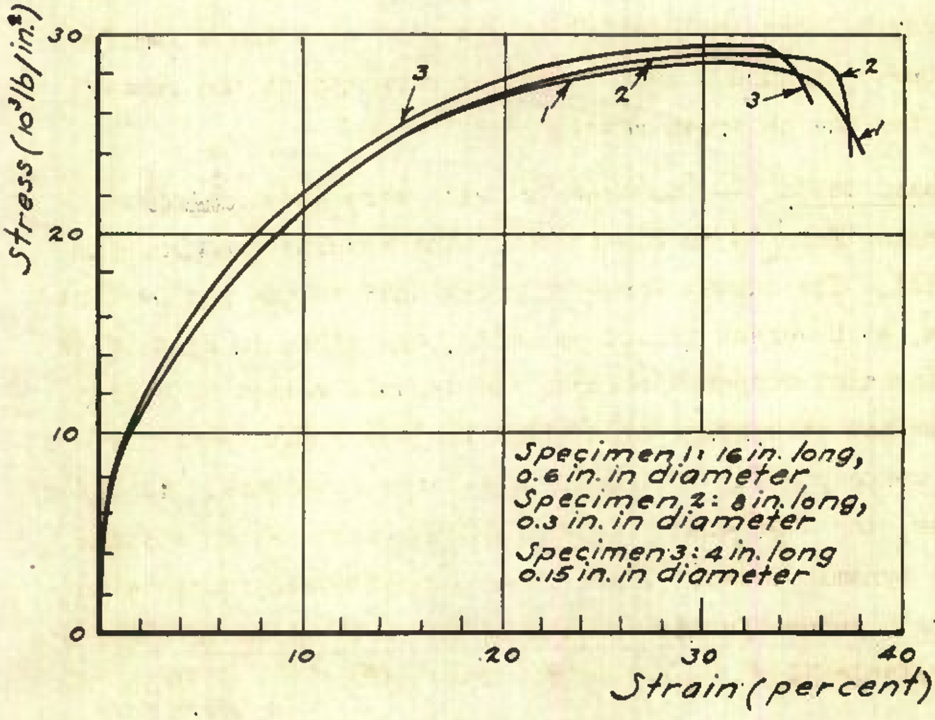

Fig. 4. Static stress-strain curves for annealed copper specimens machined from 1-in. round bar.

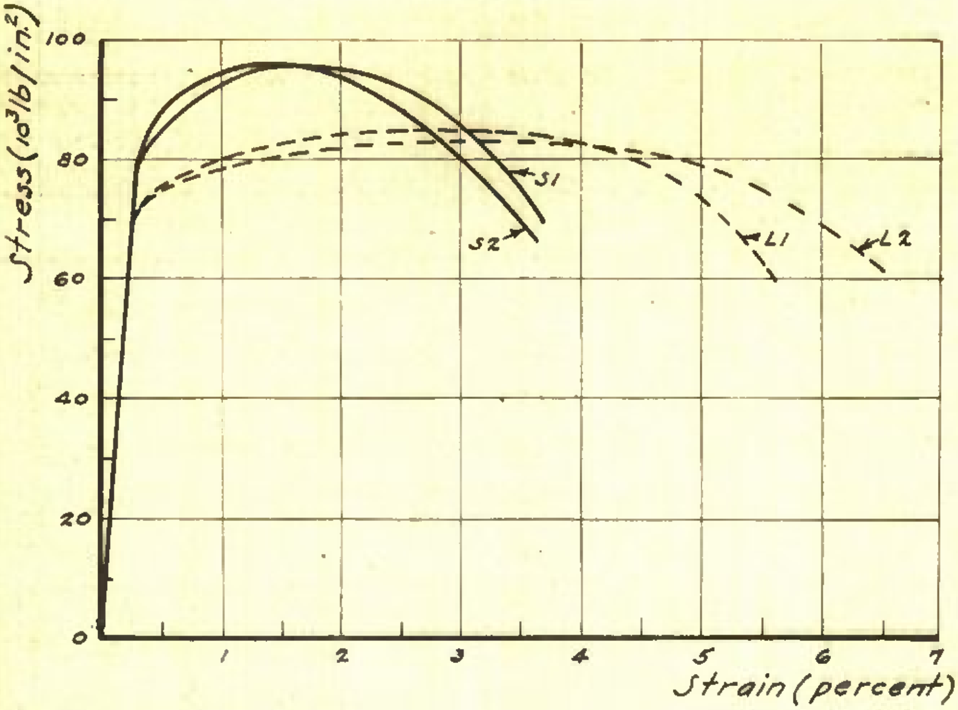

Fig. 5. Static stress-strain curves for cold-rolled steel; —— short specimens; -- long specimens; specimen numbers indicated on curves.

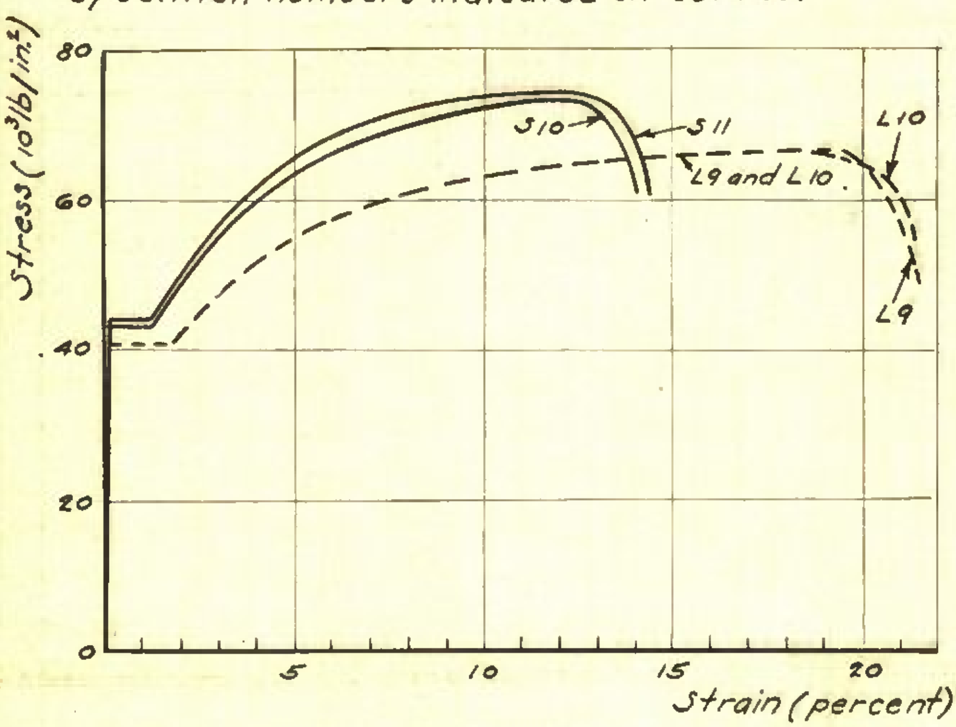

Fig. 6. Static stress-strain curves for annealed steel; —— short specimens; -- long specimens; specimen numbers indicated on curves.

Table VI. Results of dynamic tests of annealed copper.

Specimen No.	Impact Velocity (ft/sec)	Ultimate Strength (lb/in^2)	Energy per Unit Volume ($ft\ lb/in^3$)	Elongation in Gage Length (percent)	Reduction of Area (percent)	Hardness Rockwell F
Specimens 7 in. long, 0.350 in. in diameter						
1	25.0	39600	1170	43.8	67	75.9
12	25.0	41600	1130	41.3	69	75.2
4	50.2	40500	1290	46.0	69	69.8
11	50.0	38600	1180	45.4	71	76.6
5	100.0	43000	1470	51.8	73	72.7
10	100.0	43000	1370	48.2	67	69.4
6	151.0	39000	1310	50.0	72	74.0
9	150.8	37200	1280	49.0	73	73.3
7	201.0	41400	1253	46.6	73	75.0
8	201.0	40300	1020	45.0	70	72.9
					Average	73.5
Specimens 2 in. long, 0.100 in. in diameter						
1	25.4	35000	930	37.0	68	34.7
10	25.5	37000	840	32.5	53	37.7
2	50.0	37000	905	34.6	68	39.2
9	50.0	37000	980	38.0	71	47.5
3	100.0	39000	1160	47.0	65-73	47.8
8	100.0	38000	1050	40.0	66	51.0
4	150.5	42000	850	34.6	65	35.2
7	150.5	40000	1000	42.0	70	37.8
5	200.0	37000	980	37.8	74	33.1
6	201.0	40700	1010	43.0	70	36.0
					Average	39.7

Table VII. Results of dynamic tests of cold-rolled steel.

Specimen No.	Impact Velocity (ft/sec)	Ultimate Strength (lb/in^2)	Energy per Unit Volume ($ft\ lb/in^3$)	Elongation in Gage Length (percent)	Reduction of Area (percent)	Hardness Rockwell B
Specimens 8 in. long, 0.300 in. in diameter						
4	25.1	---	---	11.7	65	93.6
3	25.1	104 000	516	7.9	64	94.5
5	50.0	96 000	760	10.2	76	94.4
8	75.0	110 000	1 042	12.6	66	93.5
7	75.8	---	---	13.8	67	94.5
9	100.8	104 000	11 180	15.0	65	93.1
10	125.0	106 000	1 000	12.1	69	95.9
11	151.4	108 000	730	7.8	64	93.9
13	171.5	106 000	574	6.0	61	94.0
12	177.0	---	---	5.0	61	95.0
14	199.8	108 000	443	4.3	65	93.5
						Average 94.2
Specimens 4 in. long, 0.150 in. in diameter						
3	25.3	114 000	616	7.0	58	95.6
4	50.2	113 000	675	7.4	64	94.5
5	75.3	113 000	840	9.3	60	93.8
6	100.0	119 000	765	8.1	62	94.1
8	125.0	112 000	595	5.9	60	91.3
7	126.0	---	---	6.9	57	93.7
9	150.0	124 000	524	4.3	64	95.0
10	178.0	117 000	498	4.1	65	95.1
11	202.0	115 000	447	3.9	56	94.1
						Average 94.1

Table VIII. Results of dynamic tests of annealed steel.

Specimen No.	Impact Velocity (ft/sec)	Ultimate Strength (lb/in^2)	Energy per Unit Volume ($ft\ lb/in^3$)	Elongation in Gage Length (percent)	Reduction of Aera (percent)	Hardness Rockwell B
Specimens 8 in. long, 0.300 in. in diameter						
1	24.7	90 000	1570	26.0	68	71.0
11	25.7	91 000	1880	26.2	67	71.6
2	50.0	94 300	1820	24.7	68	71.4
15	50.7	90 300	1510	22.3	69	71.7
3	74.0	91 600	1740	23.4	69	71.3
12	75.2	85 000	1470	22.9	68	72.0
13	99.0	89 300	1570	23.0	67	71.5
4	100.0	90 000	1730	24.7	68	71.8
14	125.3	91 000	1640	23.8	67	71.5
5	126.0	94 500	1790	24.6	65	71.7
6	150.0	89 200	1270	19.0	64	71.1
7	175.0	95 300	1065	15.4	67	70.8
8	201.5	88 900	612	9.7	66	71.8
					Average	71.4
Specimens 4 in. long, 0.150 in. in diameter						
12	25.0	99 200	1470	19.8	57	71.8
1	25.6	100 600	1210	15.4	60	71.8
2	49.8	107 000	1650	18.3	62	70.2
3	75.6	109 500	1720	19.2	58	70.8
5	100.0	106 200	1580	19.5	59	71.5
13	125.3	98 900	1625	22.8	59	72.0
6	128.0	110 600	1890	22.0	64	72.7
14	149.0	101 000	1820	23.2	61	72.0
7	151.0	102 500	1660	21.1	64	73.3
15	174.0	100 600	1410	19.0	51	73.2
8	177.0	109 600	1275	16.7	46	72.2
9	200.0	104 900	980	12.5	56	72.0
					Average	71.9

are given in Fig. 9. These curves are typical of a cold-rolled metal. As in the case of annealed copper, the energy per unit volume and the percentage elongation of small specimens under dynamic conditions are less than the corresponding values for the large specimens. A similar difference was also observed in the results of static tests. The dynamic ultimate strength of the small specimens is greater than that of the large specimens as indicated by the static tests.

The results of tests made on the annealed steel are given in Table VIII. The curves for the energy per unit volume and the percentage elongation, each versus impact velocity, are given in Fig. 10. Here again the results substantiate earlier indications that the difference between dynamic tensile properties of specimens of two different sizes is similar to the difference between their static tensile properties.

The measured critical velocities are given in Table V. The critical velocities computed from the static stress-strain curves by the von Kármán formula[9/] are also listed in this table. While the experimental and theoretical values are about the same for the cold-rolled steel, a discrepancy exists between these values for the annealed steel. This discrepancy may be attributed to the existence of a yield point in the annealed steel as discussed in previous reports. For materials of this type the computed critical velocity should be considered only as an indication.

The difference between the critical velocity obtained in the tests on the two sizes of specimens may be attributed to the different properties of the material in the two sizes of specimens. The difference in these properties was observed in the static tests. It is probable that if the structural characteristics of the two specimens were identical, thus leading to identical stress-strain diagrams, no difference would be discernable between the critical velocities determined from tests on geometrically similar specimens.

9/ Reference 6.

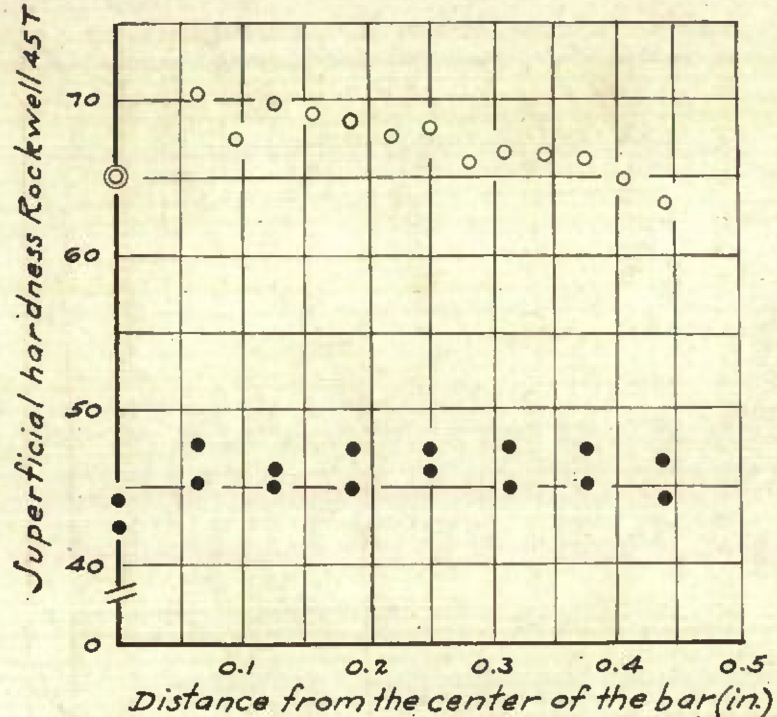

Fig. 7. Variation of superficial hardness in a cross section of a bar of cold-rolled (o) and annealed (•) steel.

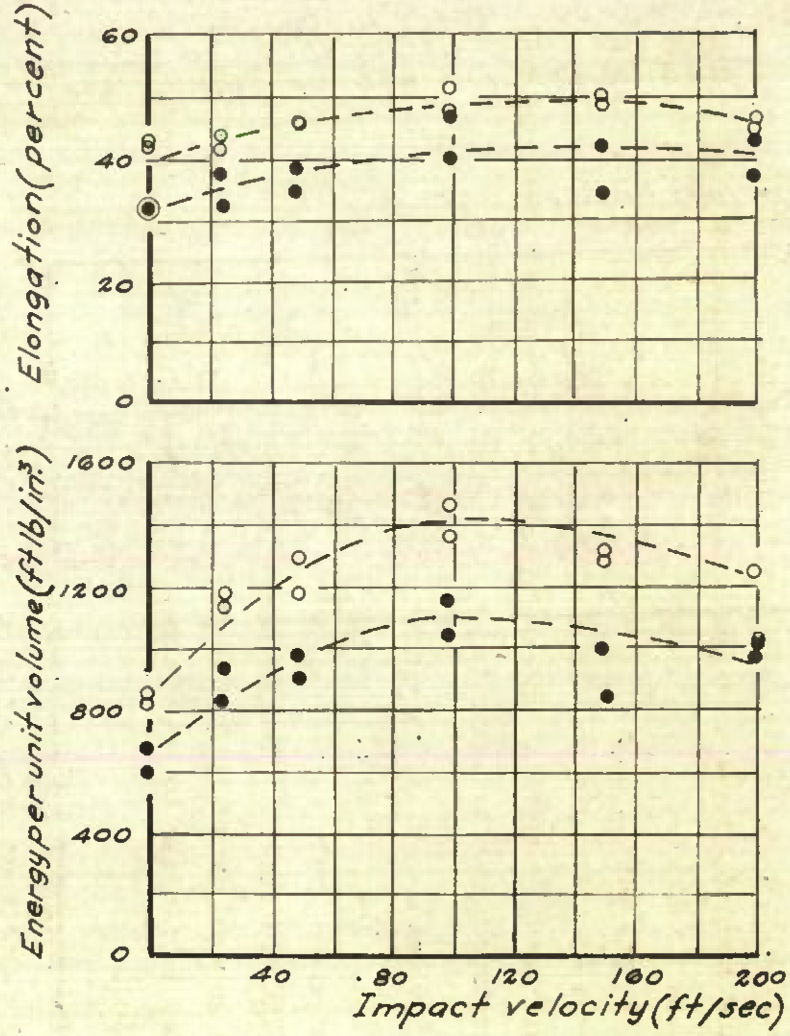

Fig. 8. Percentage elongation and specific energy, each versus impact velocity, for annealed copper; o, long specimens; •, short specimens.

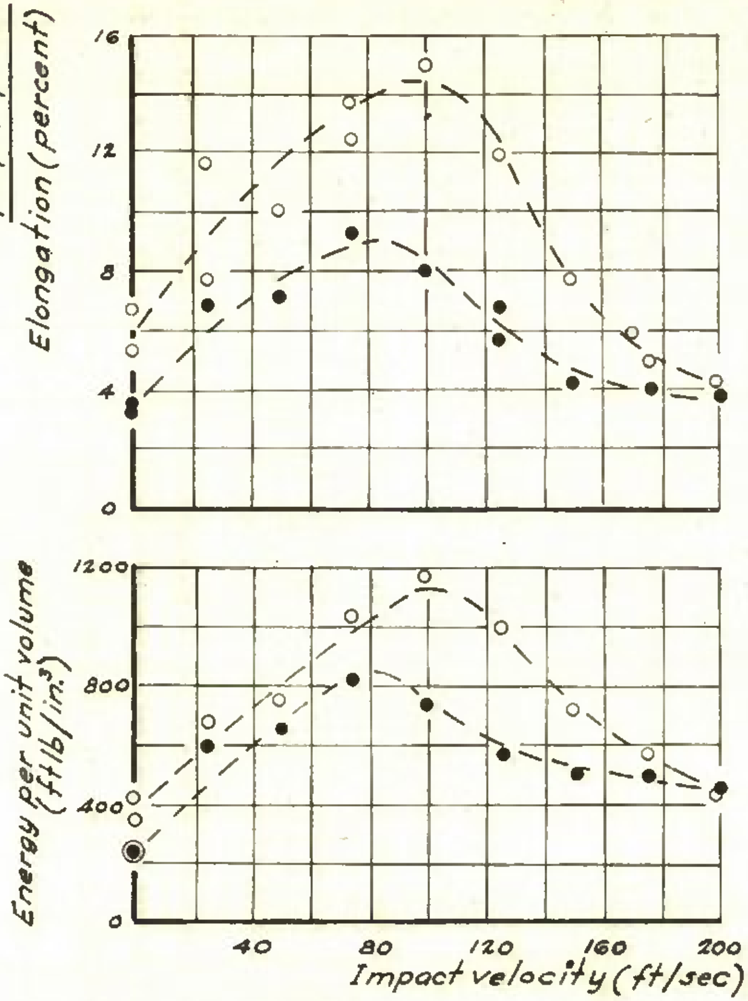

Fig. 9. Percentage elongation and specific energy, each versus impact velocity, for cold-rolled steel; o, long specimens; ●, short specimens.

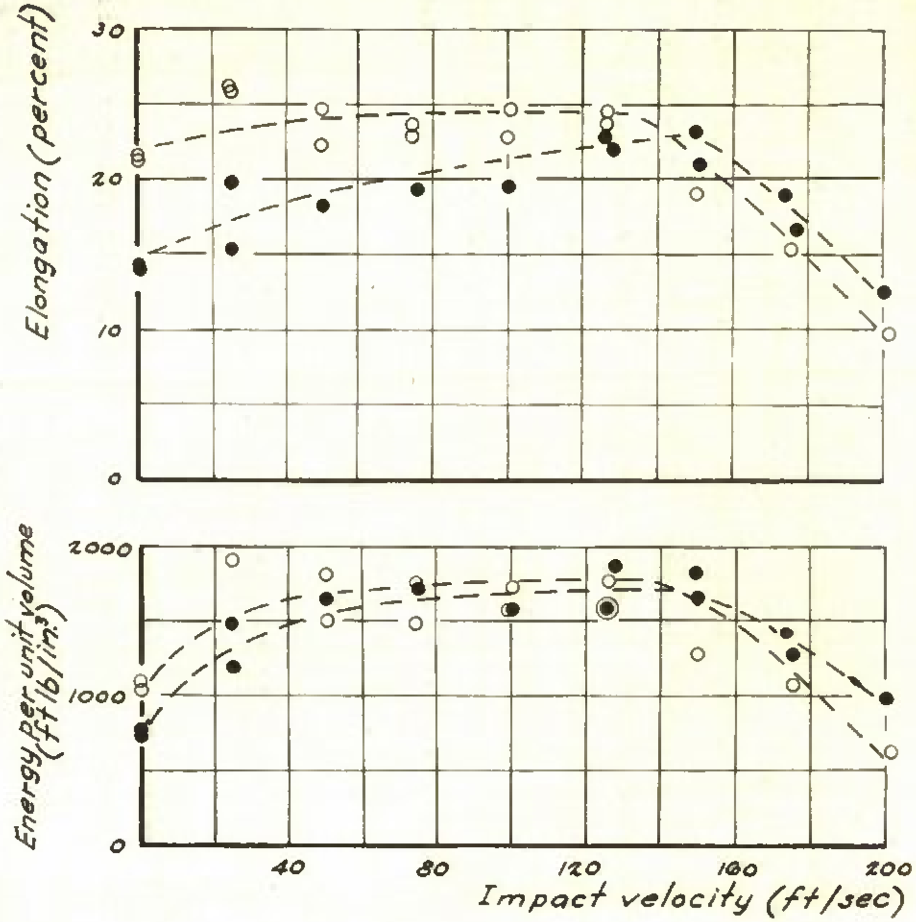

Fig. 10. Percentage elongation and specific energy, each versus impact velocity, for annealed steel; o, long specimens; ●, short specimens.

8. Conclusions

Evidence secured in this investigation points to the conclusion that within the range of impact velocities between 25 and 200 ft/sec, the size of the specimen does not alter the effect of velocity on the tensile properties of metals. This tends to show that the dynamic tensile properties are the same for the same impact velocity even though the average rate of strain is different within limits. The difference existent in the dynamic values of ultimate strength, energy per unit volume and percentage of elongation for geometrically similar specimens of two different sizes is also present for the static values and thus is not dependent upon the dynamic effect.

PART III. SHAPE OF CROSS SECTION

9. Specimens tested

Annealed copper was chosen for these experiments because of the consistency in its behavior. The specimens used were of four different cross-sectional shapes, as shown in Fig. 11. The area of the cross section for each specimen was 0.071 in^2 and the length of each was 8 in. The specimens were prepared from 5/8-in. round, hard-drawn, copper bar. The round specimens, square specimens, and 0.376 × 0.188 in. rectangular specimens were machined from the hard-drawn bar, annealed at 900°F for ½ hr and quenched in water. The rectangular specimens, 0.630 × 0.112 in., were prepared in the following manner:

(i) Bar stock cut to length, annealed at 1200°F for ½ hr and water quenched.
(ii) Forged to a flat strip 1 × 1/8-in. in section.
(iii) Annealed at 1200°F for ½ hr and water quenched.
(iv) Rolled to 0.112-in. thickness.
(v) Specimens machined from the rolled strip.
(vi) Annealed at 850°F for ½ hr and water quenched.

The temperature of the last anneal was determined experimentally as that temperature which gave the same grain size as was present in the specimens of other section shape.

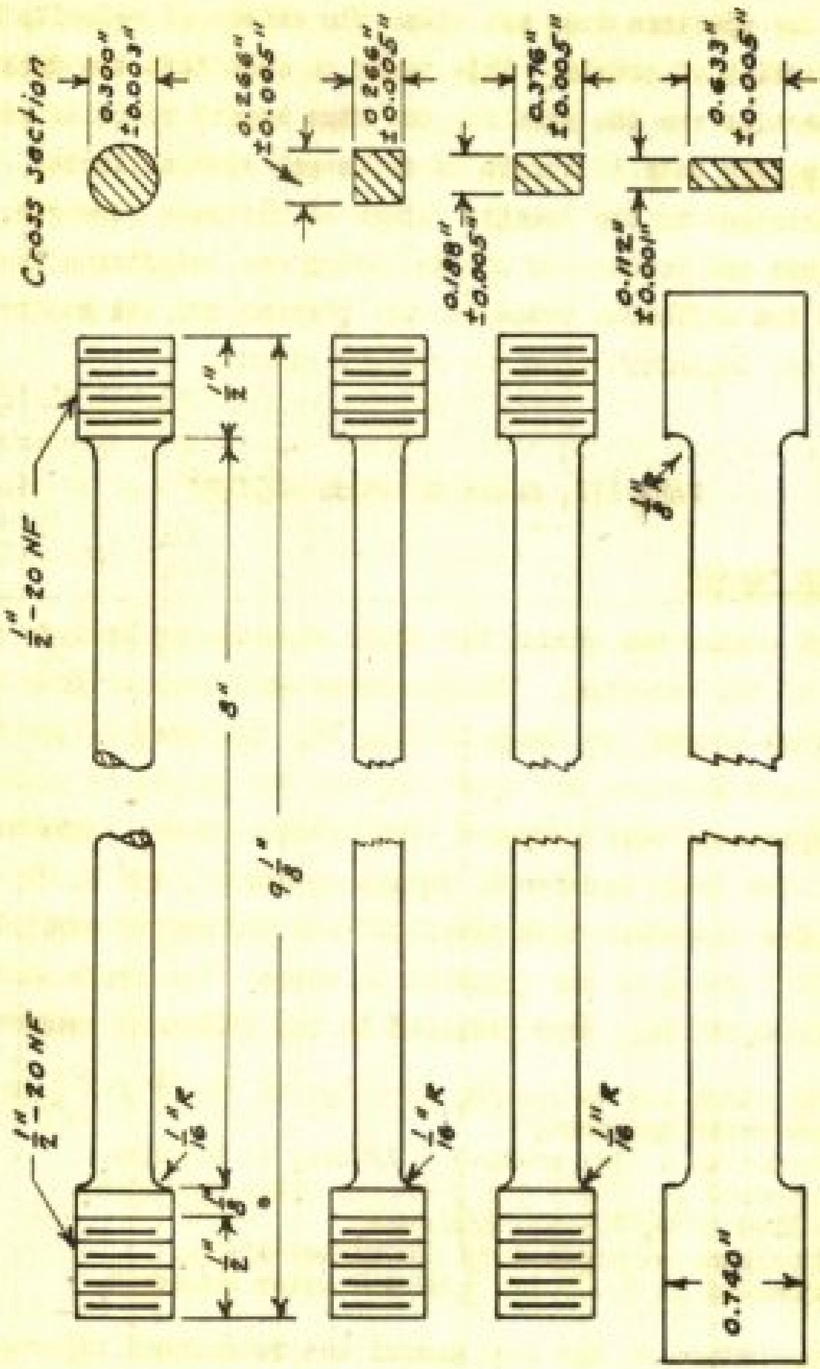

Fig. 11. Drawings of specimens used in tests on annealed copper.

10. Discussion of results

(a) Static tests. — Two static tests were made for each series of specimens. The static stress-strain curves are given in Fig. 12 and the results are given in Table IX. The difference between the static stress-strain curves of specimens of different shape of cross section is not greater than the difference found between curves corresponding to two specimens of the same shape. The shape of the cross section of the specimen does not seem to influence the results of static tests within the range of dimensions considered in this investigation.

Table IX. Results of static tests of annealed copper specimens.

Cross-sectional Dimensions	Specimen No.	Ultimate Strength (lb/in^2)	Prop. Limit (lb/in^2)	Energy per Unit Volume ($ft\ lb/in^3$)	Elongation in 8 in. (percent)	Reduction of Area (percent)	Hardness Rockwell F
0.3-in. diam.	29	30000	5000	545	29.0	65	68.3
0.3-in. diam.	30	29800	5000	718	36.5	64	67.4
0.26 × 0.26 in.	11	30000	5000	636	33.2	67	59.3
0.26 × 0.26 in.	12	29600	5000	674	35.0	68	63.6
0.186 × 0.378 in.	23	29400	5000	672	37.0	71	60.7
0.186 × 0.378 in.	24	29000	5000	590	32.0	67	62.7
0.112 × 0.633 in.	15	29800	5000	730	37.4	—	78.0
0.112 × 0.633 in.	16	30150	5000	740	38.0	—	77.6

Table X. Results of dynamic tests of annealed copper specimens of different cross-sectional shapes.

Cross Section	Specimen No.	Impact Velocity (ft/sec)	Ultimate Strength (lb/in^2)	Energy per Unit Volume (ft lb/in^3)	Elongation in 8 in. (percent)	Reduction of Area (percent)	Hardness Rockwell F
Circular; diameter, 0.300 in.	21	25.7	35000	762	34.9	68	69.2
	22	50.6	36700	1030	42.3	70	70.3
	23	75.1	38900	1070	45.8	69	65.7
	24	100.0	37200	1100	46.0	66	66.2
	25	125.5	35400	1150	50.2	71	66.7
	26	152.0	35400	1080	49.0	67	68.8
	27	176.3	37000	992	43.5	68	70.1
	28	202.0	38000	744	37.7	72	68.1
						Average	68.1
Square, 0.266 × 0.266 in.	1	25.7	36200	1140	41.0	65	65.8
	2	50.4	37800	1250	41.5	66	63.0
	9	74.6	36200	1180	41.5	72	64.3
	3	74.6	36400	1305	44.2	69	67.2
	10	101.0	37000	1180	45.5	71	64.0
	4	104.0	36000	1060	39.0	72	63.5
	5	124.8	35600	1180	41.6	69	62.5
	6	150.5	36000	1150	41.8	70	68.8
	7	175.7	37000	1225	45.0	73	66.2
	8	202.0	39000	1210	42.0	70	69.7
						Average	65.5
Rectangular; 0.188 × 0.376 in.	14	24.7	38000	1085	36.8	65	67.5
	13	25.7	---	---	38.8	67	63.7
	15	49.5	38400	1135	36.1	71	66.8
	16	74.5	40000	1400	45.3	68	66.7
	17	100.2	38000	1190	40.0	69	67.3
	18	124.7	38500	1245	41.8	65	67.0
	19	150.3	37400	1270	44.4	70	68.2
	20	173.5	37600	1380	49.0	73	66.5
	21	199.0	---	---	44.0	70	67.8
	22	201.0	38000	1230	45.5	71	71.2
						Average	67.3
Rectangular, 0.112 × 0.630 in.	5	25.4	41200	1030	39.6	--	79.5
	6	25.4	40000	985	37.0	--	80.8
	7	50.8	40400	1150	42.0	--	80.4
	17	75.1	41000	1030	40.7	--	81.4
	9	101.2	40000	910	34.2	--	81.4
	10	125.7	38500	1070	41.4	--	80.8
	11	150.5	39200	900	34.8	--	81.7
						Average	80.7

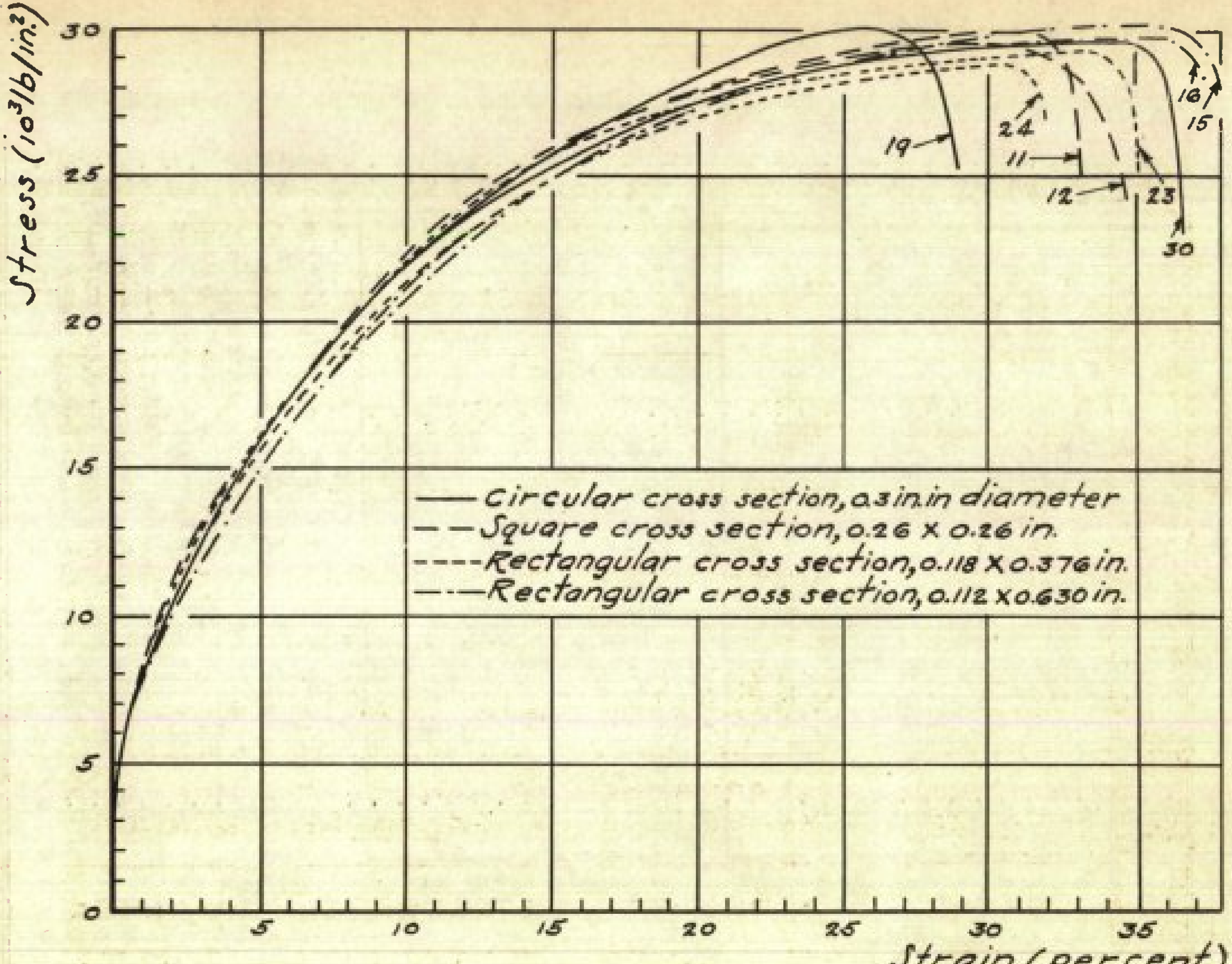

Fig. 12. Static stress-strain curves for annealed copper; specimens were 8 in. in length and were of different cross-sectional shapes.

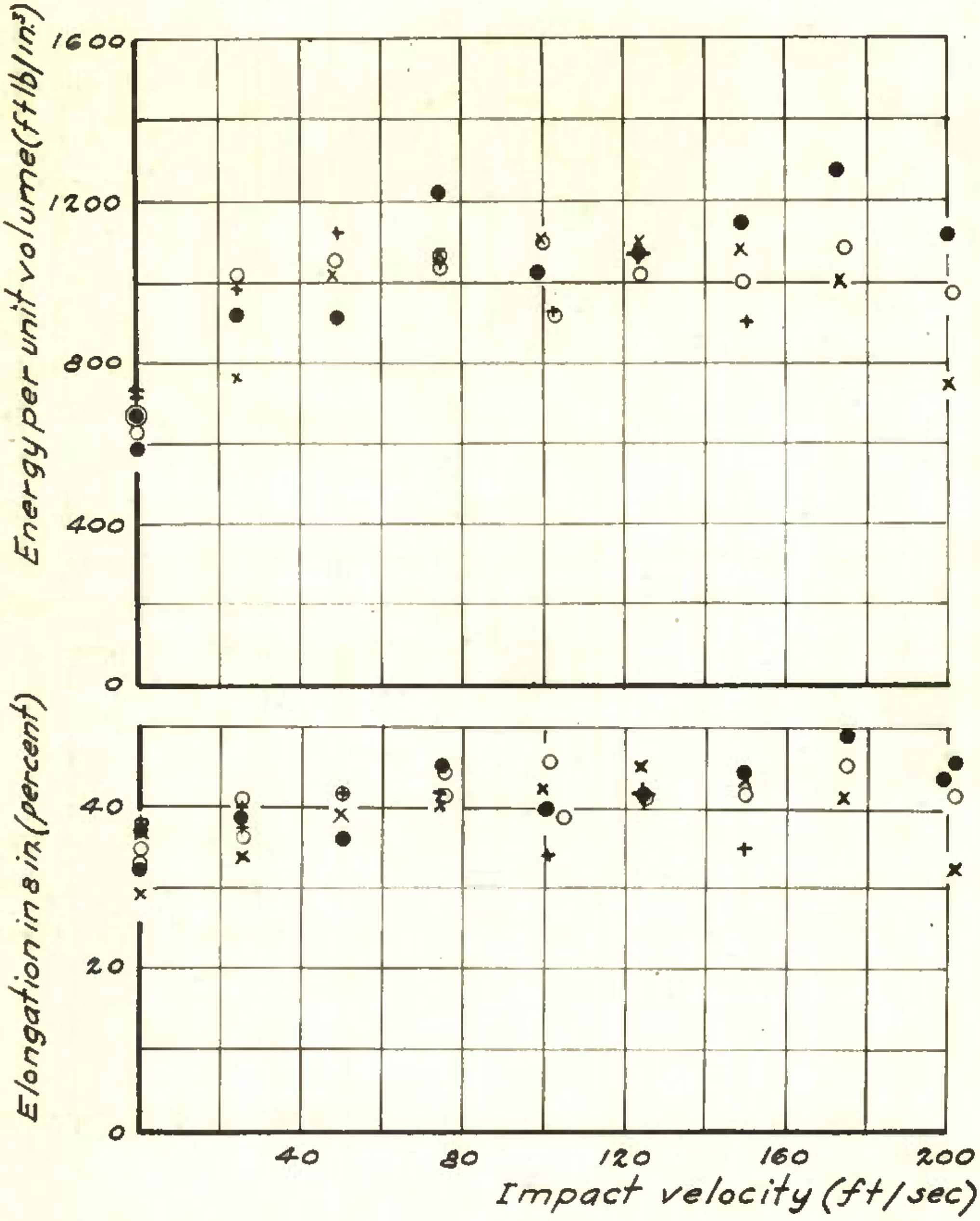

Fig. 13. Specific energy and percentage elongation, each versus impact velocity, for annealed copper; specimens were 8 in. in length and were of different cross-sectional shapes. ●, circular cross section, 0.3 in. in diameter; o, square cross section, 0.26 x 0.26 in.; x, rectangular cross section, 0.188 x 0.376 in.; +, rectangular cross section, 0.112 x 0.630 in.

(b) Dynamic tests. — Dynamic tests were made at impact velocities ranging from 25 to 200 ft/sec. The ultimate strength, the percentage elongation, the energy required to break the specimen, and the reduction of area were measured. The results are given in Table X. The curves of percentage elongation and energy per unit volume required for rupture, each versus impact velocity are presented in Fig. 13. The values of ultimate strength, energy required for rupture, and percentage elongation under dynamic conditions are higher than the static values, but the increase is practically the same for all cross-sectional shapes. The difference between results is of the same order of magnitude as the scatter observed for a series of tests on any one of the cross-sectional shapes. While the critical velocity of this material is above 200 ft/sec, it is to be expected that the cross-sectional shape will not influence its value since the stress-strain diagrams are essentially the same.

11. Conclusions

The results of static and dynamic tensile tests made on specimens having the same length and the same cross-sectional area are practically independent of the shape of the cross section, within the range of dimensions considered in this investigation.

12. Summary

The results of the investigations presented in this report may be summarized as follows:

(i) The critical velocity of a material is not influenced by the length or diameter of the specimen.

(ii) In order to determine accurately the critical velocity in tension, the ratio of length to diameter of the specimen must be at least 13.

(iii) The size of the test specimen does not influence the effect of velocity on the tensile properties of metals.

(iv) The average strain rate in the range considered in this report is not a determining factor of dynamic tensile properties.

(v) The shape of the specimen cross section does not influence the effect of velocity on the tensile properties of metals.

(vi) Some indirect evidence is given to show that the shape of the specimen does not affect the value of the critical velocity.

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ABSTRACT:

The results of a study on the influence of specimen length, diameter, and cross-sectional shape on tensile impact tests are given. The effects of the ratio of length to diameter are discussed, as well as the effect of size in geometrically similar specimens, and the influence of cross-sectional shape. The results show that the effect of velocity on the tensile properties of metals is independent of both the dimensions and the cross-sectional shape of the specimen. Furthermore, the critical velocity is not altered by these variables. For a given diameter and varying gage lengths, the stress-strain curves are nearly identical up to the point where the tangent is horizontal. Beyond this point, the shape of the curves is controlled by the necking.

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